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(54) **CONTROL DEVICE AND CONTROL METHOD FOR STARTER, AND VEHICLE**

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USPC **123/179.3**; 123/179.4; 123/90.15; 701/113

(58) **Field of Classification Search**
USPC 123/179.3, 179.4, 179.16, 179.18, 123/90.15; 701/113
See application file for complete search history.

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Office Action issued Apr. 16, 2013, in Japanese Patent Application No. 2013-501058 (with English language translation).

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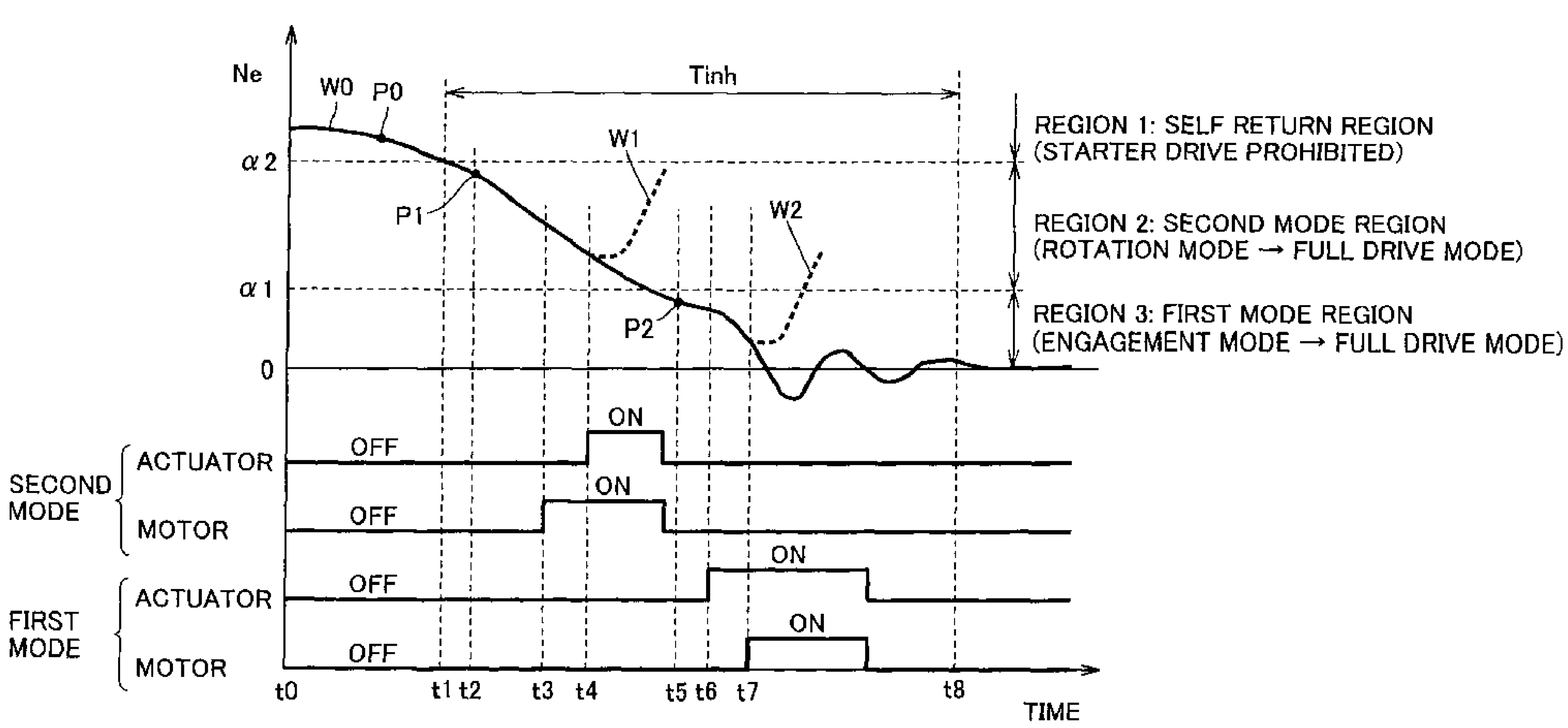
(57) **ABSTRACT**

A starter can independently drive an actuator for moving a pinion gear to a position where the pinion gear is engaged with a ring gear and a motor for rotating the pinion gear. When synchronization between the ring gear and the pinion gear is restricted, a rotation mode in which the pinion gear is rotated before the actuator is driven is restricted.

6 Claims, 7 Drawing Sheets



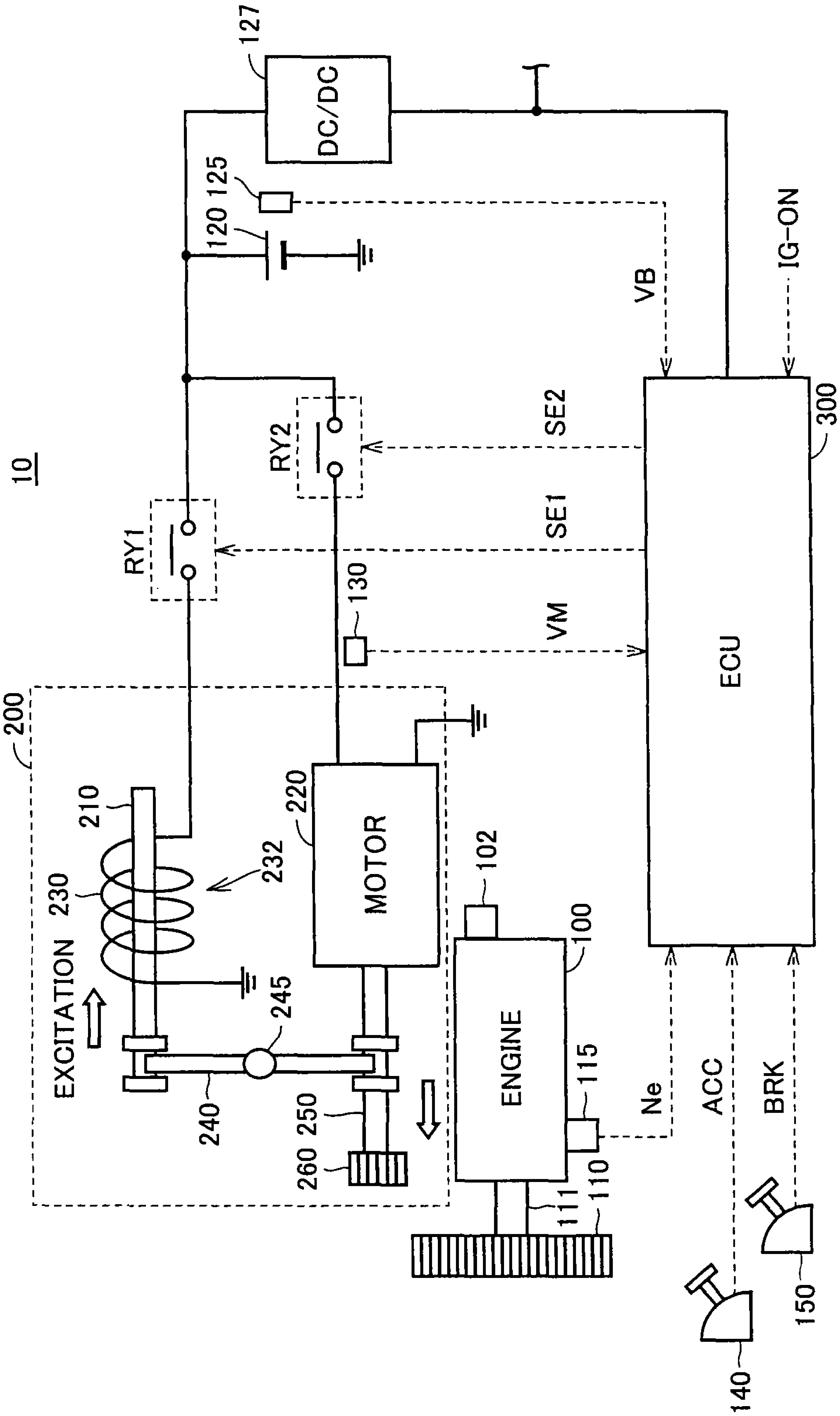

10
127
DC/DC
120 125
VB
IG-ON
RY2
SE2
RY1
SE1
130
VM
ECU
300
200
210
220
MOTOR
232
230
EXCITATION
245
102
100
ENGINE
115
240
250
260
111
110
Ne
ACC
BRK
140
150

FIG.1

FIG.2

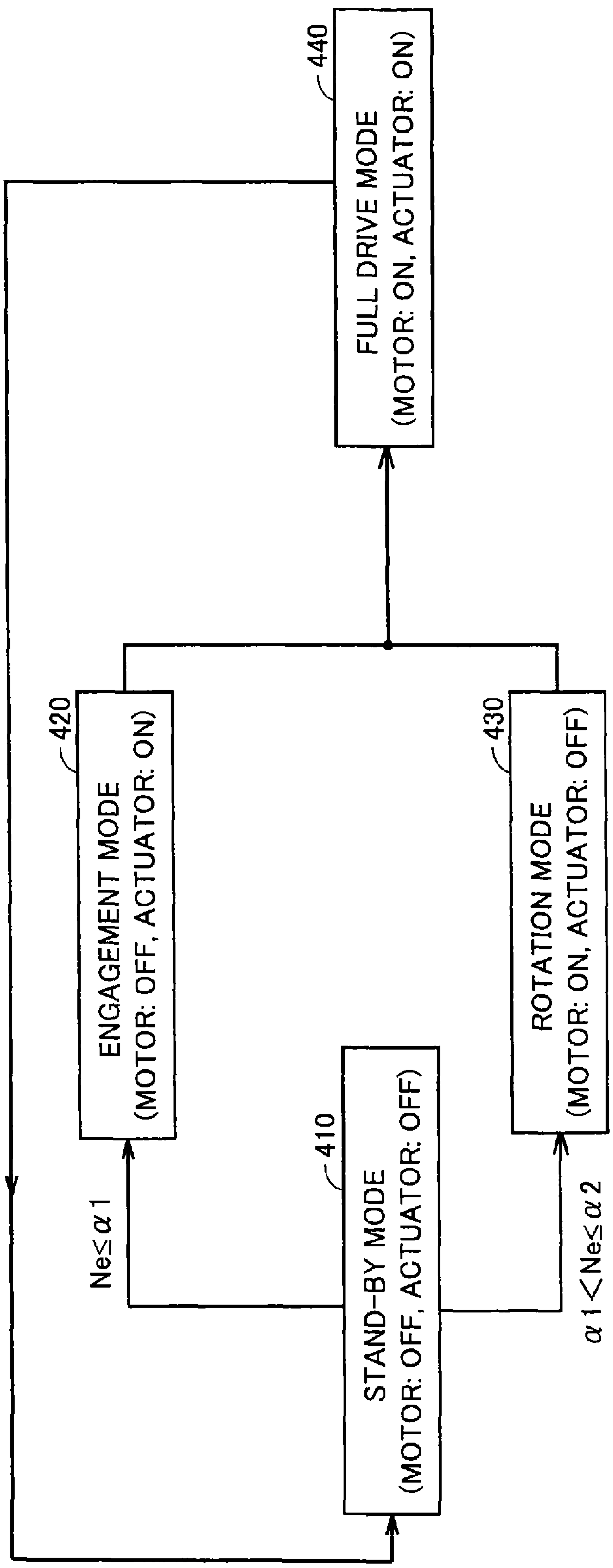
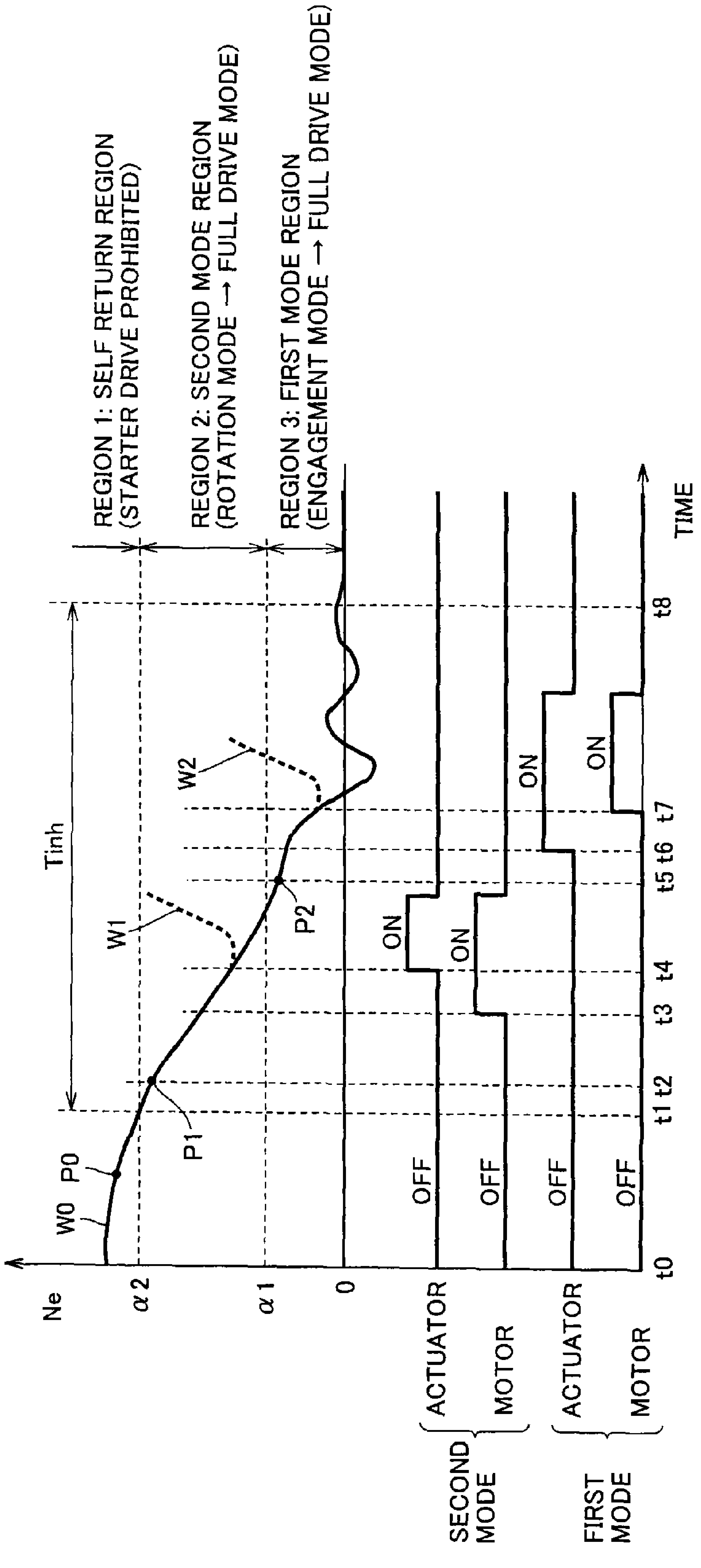

440
FULL DRIVE MODE
(MOTOR: ON, ACTUATOR: ON)
420
ENGAGEMENT MODE
(MOTOR: OFF, ACTUATOR: ON)
430
ROTATION MODE
(MOTOR: ON, ACTUATOR: OFF)
410
STAND-BY MODE
(MOTOR: OFF, ACTUATOR: OFF)
Ne≤α1
α1<Ne≤α2

FIG.3



REGION 1: SELF RETURN REGION
(STARTER DRIVE PROHIBITED)
REGION 2: SECOND MODE REGION
(ROTATION MODE → FULL DRIVE MODE)
REGION 3: FIRST MODE REGION
(ENGAGEMENT MODE → FULL DRIVE MODE)
Ne
α2
α1
0
Tinh
W0
P0
P1
W1
P2
W2
ON
OFF
SECOND MODE
ACTUATOR
MOTOR
FIRST MODE
ACTUATOR
MOTOR
t0
t1 t2
t3
t4
t5 t6
t7
t8
TIME

FIG.4

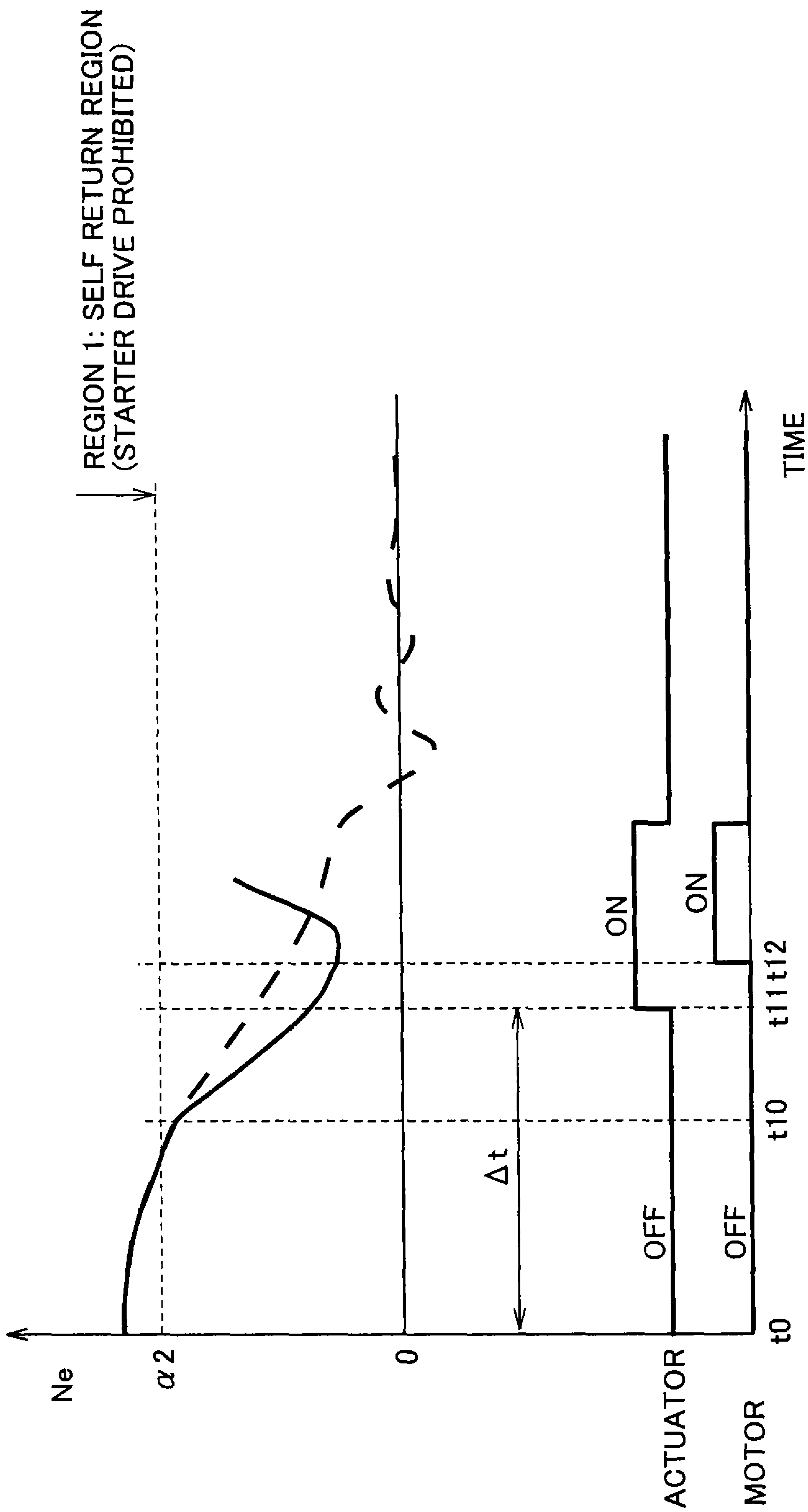
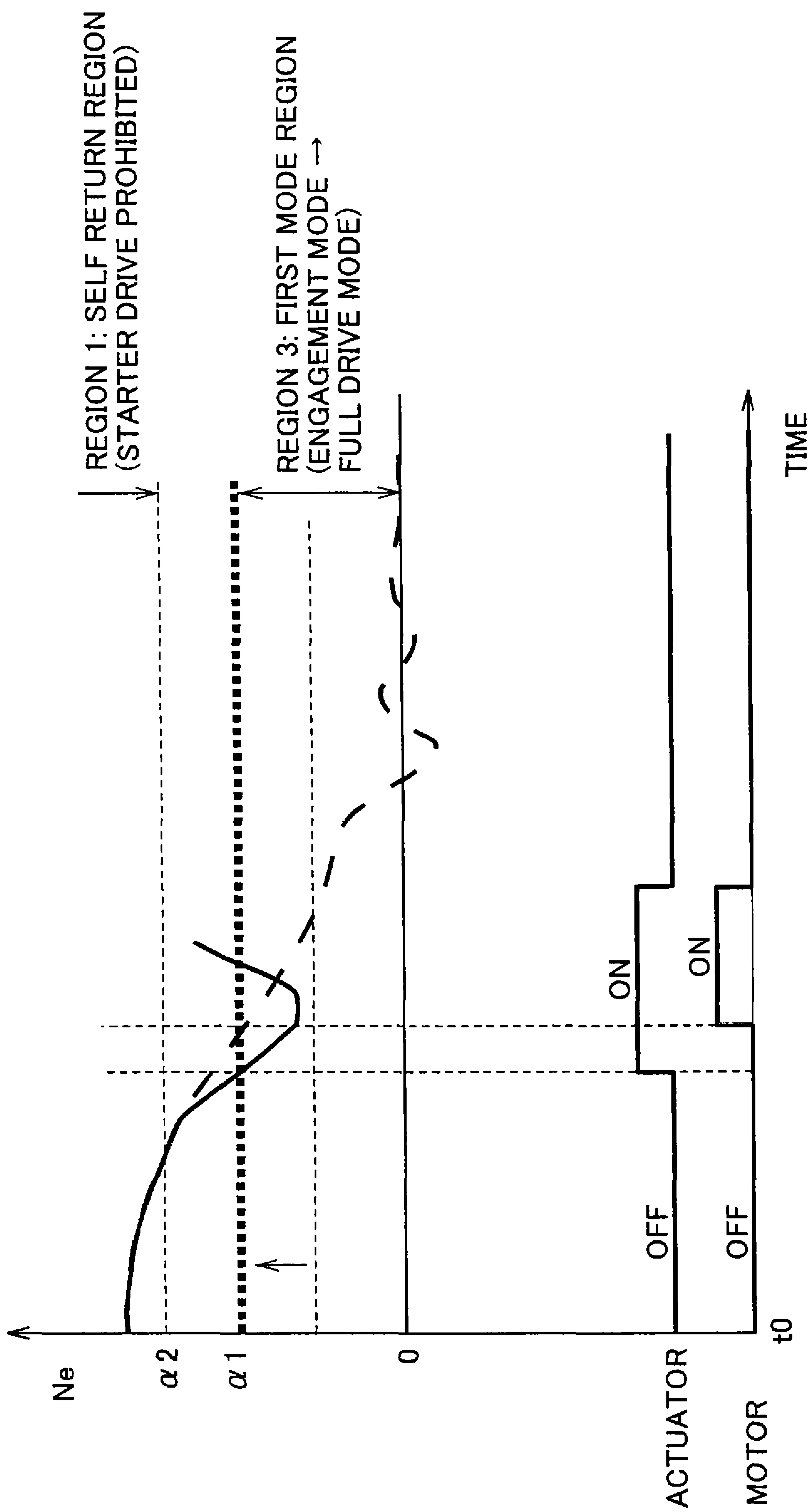

REGION 1: SELF RETURN REGION
(STARTER DRIVE PROHIBITED)
Ne
α2
0
Δt
ACTUATOR
MOTOR
OFF
OFF
ON
ON
t0
t10
t11
t12
TIME

FIG.5



REGION 1: SELF RETURN REGION
(STARTER DRIVE PROHIBITED)
REGION 3: FIRST MODE REGION
(ENGAGEMENT MODE →
FULL DRIVE MODE)
Ne
α2
α1
0
ON
ON
OFF
OFF
ACTUATOR
MOTOR
t0
TIME

FIG.6

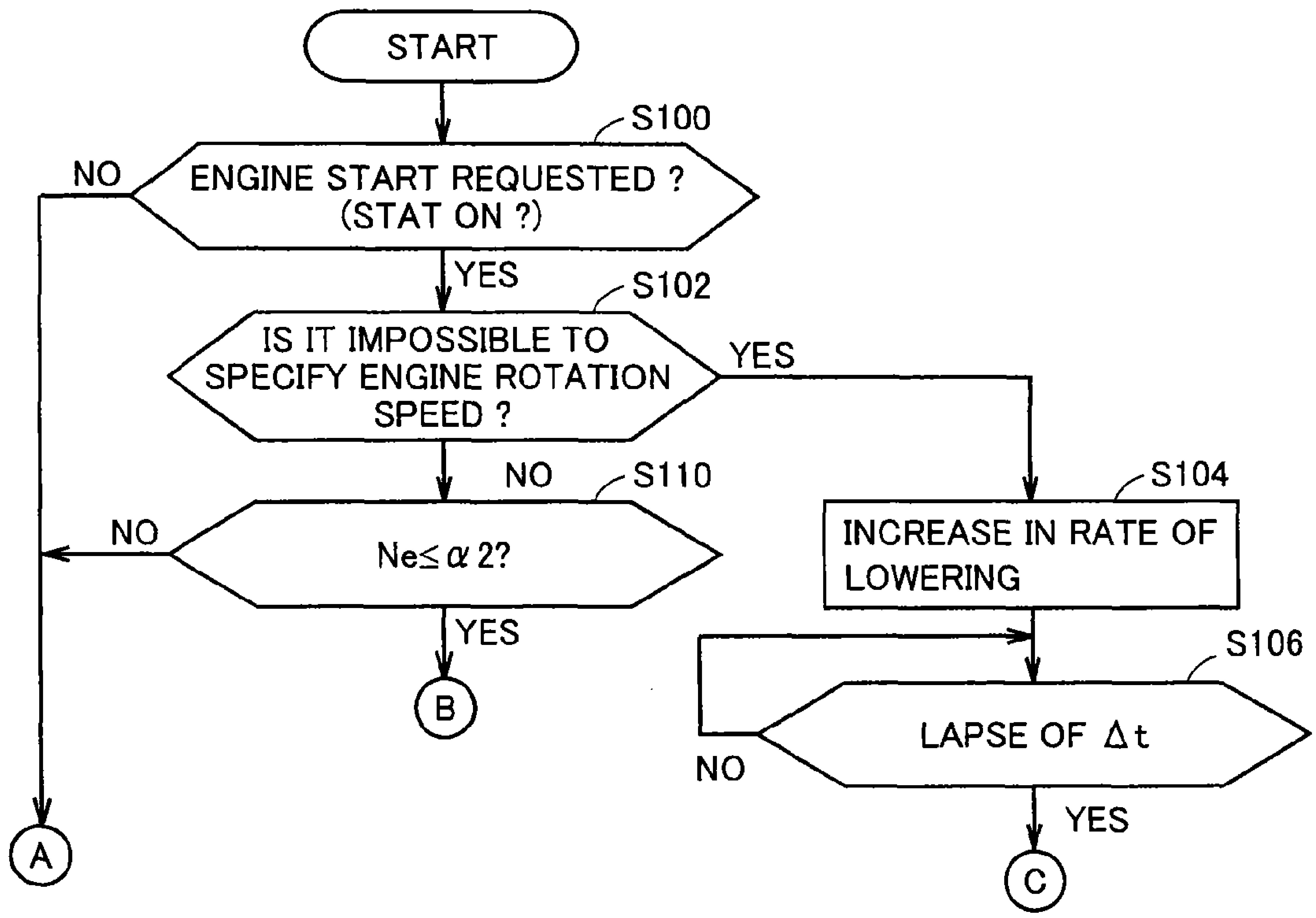
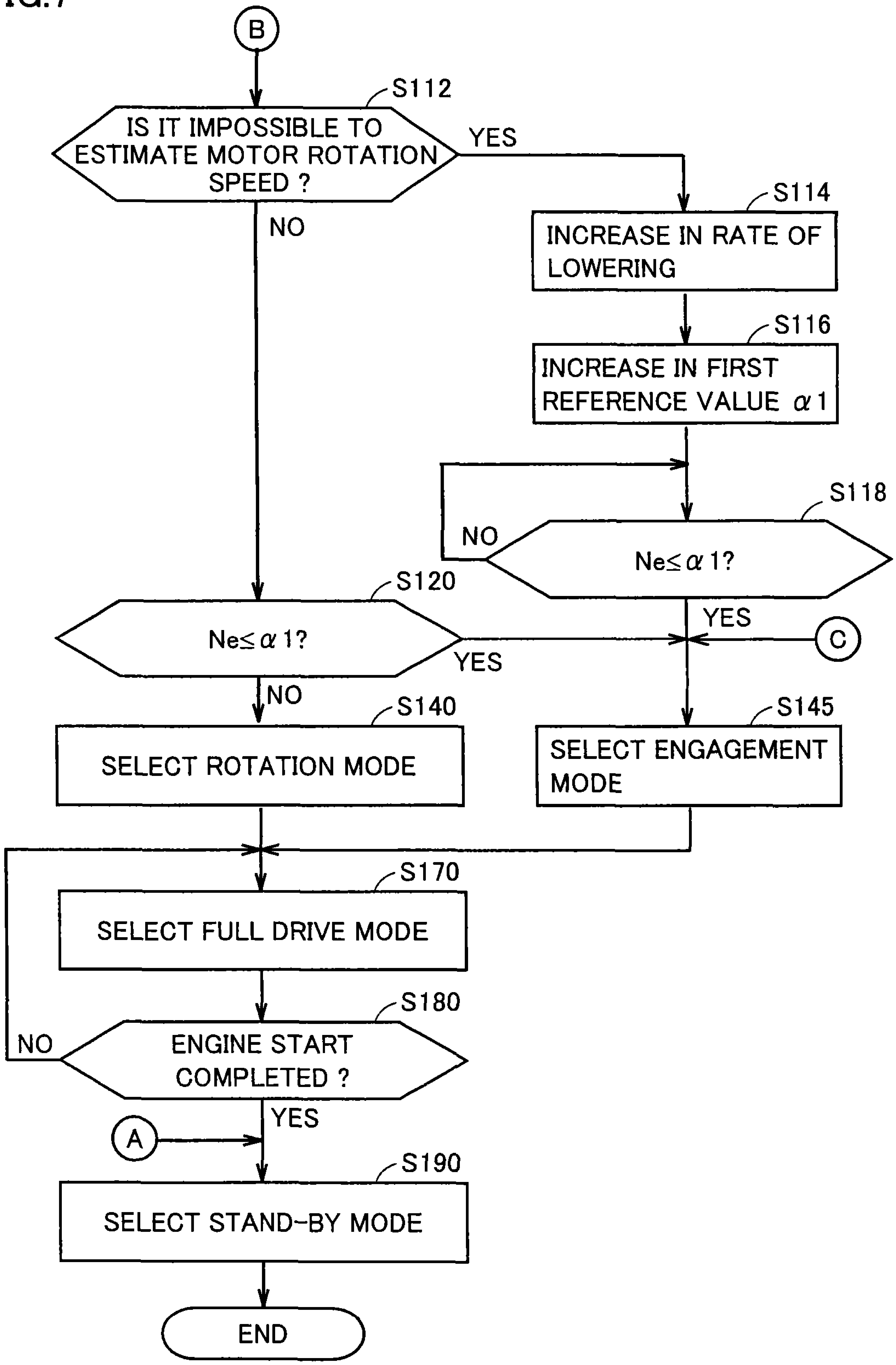

START
S100
ENGINE START REQUESTED ?
(STAT ON ?)
NO
YES
S102
IS IT IMPOSSIBLE TO
SPECIFY ENGINE ROTATION
SPEED ?
YES
NO
S110
NO
Ne≤α2?
YES
B
A
S104
INCREASE IN RATE OF
LOWERING
S106
LAPSE OF Δt
NO
YES
C

FIG.7


B
S112
IS IT IMPOSSIBLE TO ESTIMATE MOTOR ROTATION SPEED ?
YES
NO
S114
INCREASE IN RATE OF LOWERING
S116
INCREASE IN FIRST REFERENCE VALUE α1
S118
NO
Ne≤α1?
YES
C
S120
Ne≤α1?
YES
NO
S140
SELECT ROTATION MODE
S145
SELECT ENGAGEMENT MODE
S170
SELECT FULL DRIVE MODE
S180
NO
ENGINE START COMPLETED ?
YES
A
S190
SELECT STAND-BY MODE
END

CONTROL DEVICE AND CONTROL METHOD FOR STARTER, AND VEHICLE

TECHNICAL FIELD

The present invention relates to a control device and a control method for a starter, and a vehicle, and particularly to a technique for restricting rotation of a pinion gear before engagement between the pinion gear and a ring gear provided around an outer circumference of a flywheel or a drive plate of an engine.

BACKGROUND ART

In order to improve fuel efficiency or reduce exhaust emission, some cars having an internal combustion engine such as an engine include what is called an idling-stop (or economy-running) function, in which an engine is automatically stopped while a vehicle stops and a driver operates a brake pedal, and the vehicle is automatically re-started, for example, by a driver's operation for re-start such as decrease in an amount of operation of a brake pedal to zero.

In this idling-stop, the engine may be re-started while an engine rotation speed is relatively high. In such a case, with a conventional starter in which pushing-out of a pinion gear for rotating the engine and rotation of the pinion gear are caused by one drive command, the starter is driven after waiting until the engine rotation speed sufficiently lowers, in order to facilitate engagement between the pinion gear and a ring gear of the engine. Then, a time lag is caused between issuance of a request to re-start an engine and actual engine cranking, and the driver may feel uncomfortable.

In order to solve such a problem, European Patent Publication No. 2159410 (PTL 1) discloses a technique, with the use of a starter configured such that a pinion gear engagement operation and a pinion gear rotational operation can individually be performed, for causing a pinion gear to perform a rotational operation prior to the pinion gear engagement operation when a re-start request is issued while a rotation speed of an engine is being lowered.

CITATION LIST

Patent Literature

PTL 1: European Patent Publication No. 2159410

SUMMARY OF INVENTION

Technical Problem

For example, however, in a case where a rotation speed of an engine or a pinion gear cannot be detected, a case where a time from start of a pinion gear engagement operation until completion thereof varies, and the like, synchronization between a rotation speed of a ring gear and a rotation speed of the pinion gear is difficult to achieve. When the pinion gear is rotated in such a case, difference between the rotation speed of the pinion gear and the rotation speed of the ring gear may become great, contrary to the intention. Therefore, great sound is likely to be generated when the pinion gear and the ring gear are engaged with each other. In addition, the pinion gear may wear in an early stage.

An object of the present invention is to lower sound which may be generated at the time when an engine is cranked and to reduce an amount of wear of a gear.

Solution to Problem

In one embodiment, a starter includes a second gear that can be engaged with a first gear coupled to a crankshaft of an engine, an actuator that moves, in a driven state, the second gear to a position where the second gear is engaged with the first gear, and a motor that rotates the second gear. A control device for a starter includes a control unit that drives the actuator and the motor in a rotation mode in which the motor is driven before the actuator is driven. The rotation mode is restricted when synchronization between a rotation speed of the first gear and a rotation speed of the second gear is restricted.

According to this embodiment, when synchronization between the rotation speed of the first gear and the rotation speed of the second gear is restricted and consequently synchronization is difficult to achieve, the rotation mode in which the second gear is rotated before drive of the actuator for moving the second gear to the position where the second gear is engaged with the first gear is restricted. Therefore, unintended increase in difference between a rotation speed of a pinion gear and a rotation speed of a ring gear is suppressed. Consequently, sound which may be generated at the time of collision between the pinion gear and the ring gear can be lowered and an amount of wear of a gear can be decreased.

In another embodiment, when the synchronization is restricted, the actuator and the motor are driven in an engagement mode in which the second gear is engaged with the first gear.

According to this embodiment, the second gear is engaged with the first gear without rotating the second gear. Therefore, the engine can be cranked in order to satisfy a start request.

In another embodiment, when a rotation speed of the engine is higher than an upper limit value, the actuator and the motor are driven in the rotation mode. When a rotation speed of the engine is equal to or lower than the upper limit value, the actuator and the motor are driven in the engagement mode. When the synchronization is restricted, the upper limit value is increased in the second state.

According to this embodiment, the upper limit value for the engine rotation speed at which the engagement mode is carried out when synchronization is restricted is higher than the upper limit value for the engine rotation speed at which the engagement mode is carried out when synchronization is not restricted. Therefore, even though the rotation mode is restricted, the engine is quickly cranked.

In another embodiment, when a rotation speed of the engine is higher than an upper limit value, the actuator and the motor are driven in the rotation mode. When a rotation speed of the engine is equal to or lower than the upper limit value, the actuator and the motor are driven in the engagement mode. When the synchronization is restricted, a rate of lowering in rotation speed of the engine is increased in the second state.

According to this embodiment, a rate of lowering in rotation speed of the engine when synchronization is restricted is higher than a rate of lowering in rotation speed of the engine when synchronization is not restricted. Therefore, the rotation speed of the engine quickly lowers to the upper limit value for the engine rotation speed at which the engagement mode is carried out. Therefore, even though the rotation mode is restricted, the engine is quickly cranked.

Advantageous Effects of Invention

When synchronization between a rotation speed of the first gear and a rotation speed of the second gear is restricted, the rotation mode in which the second gear is rotated before drive of the actuator for moving the second gear to the position where the second gear is engaged with the first gear is restricted. Therefore, unintended increase in difference between a rotation speed of a pinion gear and a rotation speed of a ring gear is suppressed. Consequently, sound which may be generated at the time of collision between the pinion gear and the ring gear can be lowered and an amount of wear of a gear can be decreased.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is an overall block diagram of a vehicle.

FIG. **2** is a diagram for illustrating transition of an operation mode of a starter.

FIG. **3** is a diagram for illustrating a drive mode in an engine start operation.

FIG. **4** is a diagram for illustrating a drive mode at the time when it is impossible to specify a rotation speed of an engine.

FIG. **5** is a diagram for illustrating a drive mode at the time when it is impossible to estimate a rotation speed of a motor.

FIG. **6** is a flowchart (No. **1**) showing processing performed by an ECU.

FIG. **7** is a flowchart (No. **2**) showing processing performed by the ECU.

DESCRIPTION OF EMBODIMENTS

An embodiment of the present invention will be described hereinafter with reference to the drawings. In the description below, the same elements have the same reference characters allotted. Their label and function are also identical. Therefore, detailed description thereof will not be repeated.

FIG. **1** is an overall block diagram of a vehicle **10**. Referring to FIG. **1**, vehicle **10** includes an engine **100**, a battery **120**, a starter **200**, an ECU **300**, and relays RY**1**, RY**2**. Starter **200** includes a plunger **210**, a motor **220**, a solenoid **230**, a coupling portion **240**, an output member **250**, and a pinion gear **260**.

Engine **100** generates driving force for running vehicle **10**. A crankshaft **111** of engine **100** is connected to a drive wheel, with a powertrain structured to include a clutch, a reduction gear, or the like being interposed.

Engine **100** has a VVT (Variable Valve Timing) mechanism **102**. VVT mechanism **102** changes a phase of an intake valve or an exhaust valve. Engine **100** is provided with a rotation speed sensor **115**. Rotation speed sensor **115** detects a rotation speed Ne of engine **100** and outputs a detection result to ECU **300**.

Battery **120** is an electric power storage element configured such that it can be charged and can discharge. Battery **120** is configured to include a secondary battery such as a lithium ion battery, a nickel metal hydride battery, a lead-acid battery, or the like. Alternatively, battery **120** may be implemented by a power storage element such as an electric double layer capacitor.

Battery **120** is connected to starter **200** with relays RY**1**, RY**2** controlled by ECU **300** being interposed. Battery **120** supplies a supply voltage for driving to starter **200** as relays RY**1**, RY**2** are closed. It is noted that a negative electrode of battery **120** is connected to a body earth of vehicle **10**.

Battery **120** is provided with a voltage sensor **125**. Voltage sensor **125** detects an output voltage VB of battery **120** and outputs a detection value to ECU **300**.

A voltage of battery **120** is supplied to ECU **300** and such auxiliary machinery as an inverter of an air-conditioning apparatus through a DC/DC converter **127**.

Relay RY**1** has one end connected to a positive electrode of battery **120** and the other end connected to one end of solenoid **230** within starter **200**. Relay RY**1** is controlled by a control signal SE**1** from ECU **300** so as to switch between supply and cut-off of a supply voltage from battery **120** to solenoid **230**.

Relay RY**2** has one end connected to the positive electrode of battery **120** and the other end connected to motor **220** within starter **200**. Relay RY**2** is controlled by a control signal SE**2** from ECU **300** so as to switch between supply and cut-off of a supply voltage from battery **120** to motor **220**. In addition, a voltage sensor **130** is provided in a power line connecting relay RY**2** and motor **220** to each other. Voltage sensor **130** detects a motor voltage VM and outputs a detection value to ECU **300**.

As described above, supply of a supply voltage to motor **220** and solenoid **230** within starter **200** can independently be controlled by relays RY**1**, RY**2**.

Output member **250** is coupled to a rotation shaft of a rotor (not shown) within the motor, for example, by a straight spline or the like. In addition, pinion gear **260** is provided on an end portion of output member **250** opposite to motor **220**. As relay RY**2** is closed, the supply voltage is supplied from battery **120** so as to rotate motor **220**. Then, output member **250** transmits the rotational operation of the rotor to pinion gear **260**, to thereby rotate pinion gear **260**.

As described above, solenoid **230** has one end connected to relay RY**1** and the other end connected to the body earth. As relay RY**1** is closed and solenoid **230** is excited, solenoid **230** attracts plunger **210** in a direction of an arrow. Namely, plunger **210** and solenoid **230** constitute an actuator **232**.

Plunger **210** is coupled to output member **250** with coupling portion **240** being interposed. As solenoid **230** is excited, plunger **210** is attracted in the direction of the arrow. Thus, coupling portion **240** of which fulcrum **245** is fixed moves output member **250** from a stand-by position shown in FIG. **1** in a direction reverse to a direction of operation of plunger **210**, that is, a direction in which pinion gear **260** moves away from a main body of motor **220**. In addition, biasing force reverse to the arrow in FIG. **1** is applied to plunger **210** by a not-shown spring mechanism, and when solenoid **230** is no longer excited, it returns to the stand-by position.

As output member **250** thus operates in an axial direction as a result of excitation of solenoid **230**, pinion gear **260** is engaged with ring gear **110** provided around an outer circumference of a flywheel or a drive plate attached to crankshaft **111** of engine **100**. Then, as pinion gear **260** performs a rotational operation while pinion gear **260** and ring gear **110** are engaged with each other, engine **100** is cranked and started.

Thus, in the present embodiment, actuator **232** for moving pinion gear **260** so as to be engaged with ring gear **110** provided around the outer circumference of the flywheel or the drive plate of engine **100** and motor **220** for rotating pinion gear **260** are individually controlled.

Though not shown in FIG. **1**, a one-way clutch may be provided between output member **250** and a rotor shaft of motor **220** such that the rotor of motor **220** does not rotate due to the rotational operation of ring gear **110**.

In addition, actuator **232** in FIG. **1** is not limited to the mechanism as above so long as it is a mechanism capable of transmitting rotation of pinion gear **260** to ring gear **110** and switching between a state that pinion gear **260** and ring gear **110** are engaged with each other and a state that they are not engaged with each other. For example, such a mechanism that pinion gear **260** and ring gear **110** are engaged with each other as a result of movement of the shaft of output member **250** in a radial direction of pinion gear **260** is also applicable.

ECU **300** includes a CPU (Central Processing Unit), a storage device, and an input/output buffer, none of which is shown, and receives input from each sensor or provides output of a control command to each piece of equipment. It is noted that control of these components is not limited to processing by software, and a part thereof may also be constructed by dedicated hardware (electronic circuitry) and processed.

ECU **300** receives a signal ACC indicating an amount of operation of an accelerator pedal **140** from a sensor (not shown) provided on accelerator pedal **140**. ECU **300** receives a signal BRK indicating an amount of operation of a brake pedal **150** from a sensor (not shown) provided on brake pedal **150**. In addition, ECU **300** receives a start operation signal IG-ON issued in response to a driver's ignition operation or the like. Based on such information, ECU **300** generates a signal requesting start of engine **100** and a signal requesting stop thereof and outputs control signal SE**1**, SE**2** in accordance therewith, so as to control an operation of starter **200**.

For example, when such a stop condition that a vehicle stops, brake pedal **150** is operated by a driver, and stop of engine **100** is not restricted (is permitted) is satisfied, a stop request signal is generated and ECU **300** causes engine **100** to stop. Namely, when a stop condition is satisfied, fuel injection and combustion in engine **100** is stopped.

Thereafter, when such a start condition that an amount of operation of brake pedal **150** by the driver has attained to zero is satisfied, a start request signal is generated and ECU **300** drives motor **220** and cranks engine **100**. Alternatively, engine **100** may be cranked when accelerator pedal **140**, a shift lever for selecting a shift range or a gear, or a switch for selecting a vehicle running mode (such as a power mode or an eco mode) is operated.

When a condition for starting engine **100** is satisfied, ECU **300** controls actuator **232** and motor **220** in any one mode of a first mode in which actuator **232** and motor **220** are controlled such that pinion gear **260** starts to rotate after pinion gear **260** moved toward ring gear **110** and a second mode in which actuator **232** and motor **220** are controlled such that pinion gear **260** moves toward ring gear **110** after pinion gear **260** started to rotate.

As will be described later, when engine rotation speed Ne is equal to or lower than a predetermined first reference value $\alpha 1$, ECU **300** controls actuator **232** and motor **220** in the first mode. When engine rotation speed Ne is higher than first reference value $\alpha 1$, ECU **300** controls actuator **232** and motor **220** in the second mode.

FIG. **2** is a diagram for illustrating transition of an operation mode of starter **200** in the present embodiment. The operation mode of starter **200** in the present embodiment includes a stand-by mode **410**, an engagement mode **420**, a rotation mode **430**, and a full drive mode **440**.

The first mode described previously is a mode in which transition to full drive mode **440** is made via engagement mode **420**. The second mode is a mode in which transition to full drive mode **440** is made via rotation mode **430**.

Stand-by mode **410** represents such a state that neither of actuator **232** and motor **220** in starter **200** is driven, that is, a state that an engine start request to starter **200** is not output. Stand-by mode **410** corresponds to the initial state of starter **200**, and it is selected when drive of starter **200** is not necessary, for example, before an operation to start engine **100**, after completion of start of engine **100**, failure in starting engine **100**, and the like.

Full drive mode **440** represents such a state that both of actuator **232** and motor **220** in starter **200** are driven. In this full drive mode **440**, motor **220** rotates pinion gear **260** while pinion gear **260** and ring gear **110** are engaged with each other. Thus, engine **100** is actually cranked and the operation for start is started.

As described above, starter **200** in the present embodiment can independently drive each of actuator **232** and motor **220**. Therefore, in a process of transition from stand-by mode **410** to full drive mode **440**, there are a case where actuator **232** is driven prior to drive of motor **220** (that is, corresponding to engagement mode **420**) and a case where motor **220** is driven prior to drive of actuator **232** (that is, corresponding to rotation mode **430**).

Selection between these engagement mode **420** and rotation mode **430** is basically made based on rotation speed Ne of engine **100** when re-start of engine **100** is requested.

Engagement mode **420** refers to a state where only actuator **232** is driven and motor **220** is not driven. This mode is selected when pinion gear **260** and ring gear **110** can be engaged with each other even while pinion gear **260** remains stopped. Specifically, while engine **100** remains stopped or while rotation speed Ne of engine **100** is sufficiently low ($Ne \leq$ first reference value $\alpha 1$), this engagement mode **420** is selected.

Meanwhile, rotation mode **430** refers to a state where only motor **220** is driven and actuator **232** is not driven. This mode is selected, for example, when a request for re-start of engine **100** is output immediately after stop of engine **100** is requested and when rotation speed Ne of engine **100** is relatively high ($\alpha 1 < Ne \leq$ a second reference value $\alpha 2$).

Thus, when rotation speed Ne of engine **100** is high, difference in speed between pinion gear **260** and ring gear **110** is great while pinion gear **260** remains stopped, and engagement between pinion gear **260** and ring gear **110** may become difficult. Therefore, in rotation mode **430**, only motor **220** is driven prior to drive of actuator **232**, so that a rotation speed of ring gear **110** and a rotation speed of pinion gear **260** are in synchronization with each other. Then, in response to difference between the rotation speed of ring gear **110** and the rotation speed of pinion gear **260** being sufficiently small, actuator **232** is driven and ring gear **110** and pinion gear **260** are engaged with each other. Then, the operation mode makes transition from rotation mode **430** to full drive mode **440**.

In the case of full drive mode **440**, the operation mode returns from full drive mode **440** to stand-by mode **410** in response to completion of start of engine **100** and start of a self-sustained operation of engine **100**.

Thus, when a signal requesting start of engine **100** is output, that is, when it is determined that engine **100** is to be started, actuator **232** and motor **220** are controlled in any one mode of the first mode in which transition to full drive mode **440** is made via engagement mode **420** and the second mode in which transition to full drive mode **440** is made via rotation mode **430**.

FIG. **3** is a diagram for illustrating two drive modes (the first mode, the second mode) in an engine start operation in the present embodiment.

In FIG. **3**, the abscissa indicates time and the ordinate indicates rotation speed Ne of engine **100** and a state of drive of actuator **232** and motor **220** in the first mode and the second mode.

A case where, at a time t**0**, for example, such a stop condition that the vehicle stops and the driver operates brake pedal **150** is satisfied and consequently a request to stop engine **100** is generated and engine **100** is stopped (fuel injection and ignition are stopped) is considered. Here, unless engine **100** is re-started, rotation speed Ne of engine **100** gradually lowers as shown with a solid curve WO and finally rotation of engine **100** stops.

Then, a case where, for example, such a start condition that an amount of the driver's operation of brake pedal **150** attains to zero while rotation speed Ne of engine **100** is lowering is satisfied and thus a request to re-start engine **100** is generated is considered. Here, categorization into three regions based on rotation speed Ne of engine **100** is made.

A first region (region **1**) refers to a case where rotation speed Ne of engine **100** is higher than second reference value α**2**, and for example, such a state that the start condition is satisfied and a request for re-start is generated at a point PO in FIG. **3**.

This region **1** is a region where engine **100** can be started by a fuel injection and ignition operation without using starter **200** because rotation speed Ne of engine **100** is sufficiently high. Namely, region **1** is a region where engine **100** can return by itself. Therefore, in region **1**, drive of starter **200** is restricted, or more specifically, prohibited. It is noted that second reference value α**2** described above may be restricted depending on a maximum rotation speed of motor **220**.

A second region (region **2**) refers to a case where rotation speed Ne of engine **100** is located between first reference value α**1** and second reference value α**2**, and such a state that the start condition is satisfied and a request for re-start is generated at a point P**1** in FIG. **3**.

This region **2** is a region where rotation speed Ne of engine **100** is relatively high, although engine **100** cannot return by itself. In this region, the rotation mode is selected as described with reference to FIG. **2**.

When a request to re-start engine **100** is generated at a time t**2**, initially, motor **220** is driven after lapse of a prescribed time period. Thus, pinion gear **260** starts to rotate. Here, a rotation speed of pinion gear **260**, that is, a rotation speed of motor **220**, is estimated based on a time period of conduction or the like. Relation between a rotation speed of motor **220** and a time period of conduction is specified in advance by a developer based on results in experiments, simulation, and the like.

Then, at a time t**4** when it is estimated that the rotation speed of ring gear **110** is in synchronization with the rotation speed of pinion gear **260**, actuator **232** is driven. Then, when ring gear **110** and pinion gear **260** are engaged with each other, engine **100** is cranked and rotation speed Ne of engine **100** increases as shown with a dashed curve W**1**. Thereafter, when engine **100** resumes the self-sustained operation, drive of actuator **232** and motor **220** is stopped.

A third region (region **3**) refers to a case where rotation speed Ne of engine **100** is lower than first reference value α**1**, and for example, such a state that the start condition is satisfied and a request for re-start is generated at a point P**2** in FIG. **3**.

This region **3** is a region where rotation speed Ne of engine **100** is low and pinion gear **260** and ring gear **110** can be engaged with each other without synchronizing pinion gear **260**. In this region, the engagement mode is selected as described with reference to FIG. **2**.

When a request to re-start engine **100** is generated at a time t**5**, initially, actuator **232** is driven after lapse of a prescribed time period. Thus, pinion gear **260** is pushed toward ring gear **110**. Motor **220** is thereafter driven (at a time t**7** in FIG. **3**). Thus, engine **100** is cranked and rotation speed Ne of engine **100** increases as shown with a dashed curve W**2**. Thereafter, when engine **100** resumes the self-sustained operation, drive of actuator **232** and motor **220** is stopped.

By thus controlling re-start of engine **100** by using starter **200** in which actuator **232** and motor **220** can independently be driven, engine **100** can be re-started in a shorter period of time than in a case of a conventional starter where an operation to re-start engine **100** was prohibited during a period (Tinh) from a rotation speed at which return of engine **100** by itself was impossible (a time t**1** in FIG. **3**) to stop of engine **100** (a time t**8** in FIG. **3**). Thus, the driver's uncomfortable feeling due to delayed re-start of the engine can be lessened.

As described above, by carrying out the rotation mode in a region where rotation speed Ne of engine **100** is intermediate between first reference value α**1** and second reference value α**2**, ring gear **110** and pinion gear **260** are brought in synchronization with each other. In the case where a rotation speed of engine **100** cannot be specified, for example, due to a communication error, failure of rotation speed sensor **115**, or the like, however, synchronization between ring gear **110** and pinion gear **260** is restricted. Namely, accuracy in synchronization between ring gear **110** and pinion gear **260** may become poor, synchronization may be difficult, or synchronization may be impossible.

In addition, similarly, in the case where a rotation speed of pinion gear **260**, that is, a rotation speed of motor **220**, cannot accurately be estimated due to a communication error, failure of various sensors, or the like, synchronization between ring gear **110** and pinion gear **260** is restricted. Moreover, in the case where relation between a rotation speed of motor **220** and a time period of conduction changes due to change in voltage characteristics of battery **120** or output characteristics of motor **220**, control of synchronization between ring gear **110** and pinion gear **260** may become poor. Therefore, synchronization between ring gear **110** and pinion gear **260** is restricted.

In the present embodiment, the rotation mode is restricted in the case where synchronization between ring gear **110** and pinion gear **260** is restricted. More specifically, the rotation mode is prohibited. When synchronization between ring gear **110** and pinion gear **260** is restricted and consequently the rotation mode is restricted, as shown with a solid line in FIG. **4**, a rate of lowering in engine rotation speed Ne is made greater than a rate of lowering in engine rotation speed Ne during normal operation shown with a dashed line. For example, a phase of an intake valve is advanced to a phase of a most advanced angle by VVT mechanism **102**, in order to increase pumping loss. Alternatively, a rate of lowering in engine rotation speed Ne may be increased by increasing load imposed by auxiliary machinery.

In particular in the case where a rotation speed of engine **100** cannot be specified, in addition to or instead of increase in rate of lowering in engine rotation speed Ne, when a time elapsed since a condition for stopping engine **100** was satisfied or a time elapsed since stop of fuel injection and ignition exceeds a prescribed time period Δt, the engagement mode is selected.

Therefore, as shown in FIG. **4**, when a request for re-starting engine **100** is generated at a time t**10** and when a time elapsed since a condition for stopping engine **100** was satisfied or a time elapsed since stop of fuel injection and ignition exceeds prescribed time period Δt at a time t**11**, actuator **232** is driven. Thereafter, motor **220** is driven (a time t**12** in FIG. **4**). Engine **100** is thus cranked and rotation speed Ne of engine **100** increases. Thereafter, when engine **100** resumes the self-sustained operation, drive of actuator **232** and motor **220** is stopped. Prescribed time period Δt is predetermined by a developer based on experiments and simulation, as a time period required for engine rotation speed Ne to sufficiently become low. For example, prescribed time period Δt is determined as a time period required for engine rotation speed Ne to lower to first reference value α**1** or lower.

On the other hand, in particular in a case where a rotation speed of motor **220** cannot be estimated although a rotation speed of engine **100** can be specified, in addition to or instead of increase in rate of lowering in engine rotation speed Ne, first reference value α**1** is increased as shown in FIG. **5**.

Processing performed by ECU **300** for starting engine **100** after a condition for stopping engine **100** is satisfied will be described below with reference to FIGS. **6** and **7**. The flowcharts shown in FIGS. **6** and **7** are realized by executing a program stored in advance in ECU **300** in a prescribed cycle. Alternatively, regarding some steps, processing can also be performed by constructing dedicated hardware (electronic circuitry).

In step (hereinafter the step being abbreviated as S) **100**, ECU **300** determines whether or not a condition for starting engine **100** has been satisfied or not. Namely, whether or not to start engine **100** is determined. When a condition for starting engine **100** is not satisfied (NO in S**100**), the process proceeds to S**190** and ECU **300** selects the stand-by mode as the operation mode for starter **200** because an operation to start engine **100** is not necessary.

When a condition for starting engine **100** is satisfied (YES in S**100**), the process proceeds to S**102**. In S**102**, ECU **300** determines whether or not it is impossible to specify rotation speed Ne of engine **100**. When a communication error, failure of rotation speed sensor **115**, or the like is detected, it is determined that it is impossible to specify a rotation speed of engine **100**. It is noted that, since whether or not it is impossible to specify rotation speed Ne of engine **100** should only be determined by making use of a well-known, general technique, detailed description thereof will not be repeated here.

When it is impossible to specify rotation speed Ne of engine **100** (YES in S**102**), in S**104**, ECU **300** increases a rate of lowering in rotation speed Ne of engine **100**. Thereafter, when a time elapsed since a stop condition was satisfied or a time elapsed since stop of fuel injection and ignition exceeds prescribed time period Δt (YES in S**104**), the process proceeds to S**145**.

In S**145**, ECU **300** selects the engagement mode as the operation mode for starter **200**. Then, ECU **300** outputs control signal SE**1** so as to close relay RY**1**, and thus actuator **232** is driven. Here, motor **220** is not driven.

Thereafter, the process proceeds to S**170** and ECU **300** selects the full drive mode as the operation mode for starter **200**. Then, starter **200** starts cranking of engine **100**.

Then, in S**180**, ECU **300** determines whether or not start of engine **100** has been completed. Determination of completion of start of engine **100** may be made, for example, based on whether or not the engine rotation speed is higher than a threshold value γ indicating the self-sustained operation after lapse of a prescribed period of time since start of drive of motor **220**.

When start of engine **100** has not been completed (NO in S**180**), the process returns to S**170** and cranking of engine **100** is continued. When start of engine **100** has been completed (YES in S**180**), the process proceeds to S**190** and ECU **300** selects the stand-by mode as the operation mode for starter **200**.

When it is possible to specify rotation speed Ne of engine **100** (NO in S **102**), the process proceeds to S**110** and ECU **300** then determines whether or not rotation speed Ne of engine **100** is equal to or lower than second reference value α**2**.

When rotation speed Ne of engine **100** is higher than second reference value α**2** (NO in S**110**), engine rotation speed Ne corresponds to region **1** in FIG. **3** where engine **100** can return by itself. Therefore, ECU **300** causes the process to proceed to S**190** and selects the stand-by mode. Thereafter, ECU **300** resumes fuel injection and combustion in order to re-start engine **100**.

When rotation speed Ne of engine **100** is equal to or lower than second reference value α**2** (YES in S**110**), the process proceeds to S**112**. In S**112**, ECU **300** determines whether or not it is impossible to estimate a rotation speed of motor **220**. When a communication error, failure of various sensors (such as a current sensor of battery **120**), or the like is detected, it is determined that it is impossible to estimate a rotation speed of motor **220**. It is noted that a method for determining whether or not it is impossible to estimate a rotation speed of motor **220** is not limited as such.

When it is possible to estimate a rotation speed of motor **220** (NO in S**112**), in S**120**, ECU **300** determines whether or not rotation speed Ne of engine **100** is equal to or lower than first reference value α**1**.

A case where rotation speed Ne of engine **100** is equal to or lower than first reference value α**1** (YES in S**120**) corresponds to region **1** in FIG. **4**, and therefore the process proceeds to S**145** and ECU **300** selects the engagement mode. Then, ECU **300** outputs control signal SE**1** so as to close relay RY**1**, and thus actuator **232** is driven. Here, motor **220** is not driven.

Thereafter, the process proceeds to S**170** and ECU **300** selects the full drive mode. Then, starter **200** starts cranking of engine **100**. When start of engine **100** has not been completed (NO in S**180**), the process returns to S**170** and cranking of engine **100** is continued. When start of engine **100** has been completed (YES in S**180**), the process proceeds to S**190** and ECU **300** selects the stand-by mode.

On the other hand, when rotation speed Ne of engine **100** is higher than first reference value α**1** (NO in S**120**), the process proceeds to S**140** and ECU **300** selects the rotation mode. Then, ECU **300** outputs control signal SE**2** so as to close relay RY**2**, and thus motor **220** is driven. Here, actuator **232** is not driven.

Then, ECU **300** selects in S**170** the full drive mode. Thus, actuator **232** is driven, pinion gear **260** and ring gear **110** are engaged with each other, and engine **100** is cranked. When start of engine **100** has not been completed (NO in S**180**), the process returns to S**170** and cranking of engine **100** is continued. When start of engine **100** has been completed (YES in S**180**), the process proceeds to S**190** and ECU **300** selects the stand-by mode.

When it is impossible to estimate a rotation speed of motor **220** (YES in S **112**), in S**114**, ECU **300** increases a rate of lowering in rotation speed Ne of engine **100**. In addition, in S**116**, ECU **300** increases first reference value Δ**1**. Thereafter, when rotation speed Ne of engine **100** lowers to first reference value Δ**1** or lower (YES in S**118**), the engagement mode is selected in S**145**. Thereafter, the process proceeds to S**170** and ECU **300** selects the full drive mode. Then, starter **200** starts cranking of engine **100**. When start of engine **100** has been completed (YES in S**180**), the process proceeds to S**190** and ECU **300** selects the stand-by mode.

It is noted that, when it is impossible to estimate a rotation speed of motor **220**, only first reference value Δ**1** may be changed, for example, increased, without changing a rate of lowering in rotation speed Ne of engine **100**.

As described above, in the present embodiment, in the case where synchronization between ring gear **110** and pinion gear **260** is restricted, the rotation mode in which pinion gear **260** is rotated before drive of actuator **232** for moving pinion gear **260** to the position where pinion gear **260** is engaged with ring gear **110** is restricted. Therefore, unintended increase in difference between the rotation speed of ring gear **110** and the rotation speed of pinion gear **260** can be avoided.

It should be understood that the embodiments disclosed herein are illustrative and non-restrictive in every respect. The scope of the present invention is defined by the terms of the claims, rather than the description above, and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

Reference Signs List

10 vehicle; **100** engine; **102** VVT mechanism; **110** ring gear; **111** crankshaft; **115** rotation speed sensor; **120** battery; **125**, **130** voltage sensor; **140** accelerator pedal; **150** brake pedal; **160** powertrain; **170** drive wheel; **200**, **202** starter; **210** plunger; **220** motor; **230** solenoid; **232** actuator; **240** coupling portion; **245** fulcrum; **250** output member; **260** pinion gear; **270** one-way clutch; **300** ECU; **410** stand-by mode; **420** engagement mode; **430** rotation mode; **440** full drive mode; and RY**1**, RY**2** relay.

The invention claimed is:

1. A control device for a starter, said starter including a second gear that can be engaged with a first gear coupled to a crankshaft of an engine, an actuator that moves, in a driven state, said second gear to a position where said second gear is engaged with said first gear, and a motor that rotates said second gear, comprising:

a control unit that drives said actuator and said motor in a rotation mode in which said motor is driven before said actuator is driven, wherein

said rotation mode is restricted when a rotation speed of said engine cannot be determined,

a phase of an intake valve of said engine is advanced when a rotation speed of said engine cannot be determined, and

said actuator and said motor are driven in an engagement mode in which said second gear is engaged with said first gear when a rotation speed of said engine is equal to or lower than an upper limit value.

2. The control device for a starter according to claim **1**, wherein when a rotation speed of said engine cannot be determined, said upper limit value is increased.

3. A method of controlling a starter, said starter including a second gear that can be engaged with a first gear coupled to a crankshaft of an engine, an actuator that moves, in a driven state, said second gear to a position where said second gear is engaged with said first gear, and a motor that rotates said second gear, comprising the steps of:

driving said actuator and said motor in a rotation mode in which said motor is driven prior to drive of said actuator;

restricting said rotation mode when a rotation speed of said engine cannot be determined;

advancing a phase of an intake valve of said engine when a rotation speed of said engine cannot be determined; and

driving said actuator and said motor in an engagement mode in which said second gear is engaged with said first gear when a rotation speed of said engine is equal to or lower than an upper limit value.

4. A vehicle, comprising:

an engine;

a starter including a second gear that can be engaged with a first gear coupled to a crankshaft of said engine, an actuator that moves, in a driven state, said second gear to a position where said second gear is engaged with said first gear, and a motor that rotates said second gear; and

a control unit that drives said actuator and said motor in a rotation mode in which said motor is driven before said actuator is driven, wherein

said rotation mode is restricted when a rotation speed of said engine cannot be determined,

a phase of an intake valve of said engine is advanced when a rotation speed of said engine cannot be determined, and

said actuator and said motor are driven in an engagement mode in which said second gear is engaged with said first gear when a rotation speed of said engine is equal to or lower than an upper limit value.

5. A control device for a starter, said starter including a second gear that can be engaged with a first gear coupled to a crankshaft of an engine, an actuator that moves, in a driven state, said second gear to a position where said second gear is engaged with said first gear, and a motor that rotates said second gear, comprising:

a control unit that executes a rotation mode in which said motor is driven before said actuator is driven, wherein

when a rotation speed of said engine cannot be determined, a rate of lowering in engine rotation speed is increased to be greater than a rate of lowering in engine rotation speed when a rotation speed of said engine can be determined and said control unit executes an engagement mode in which said actuator is driven before said motor is driven.

6. The control device for a starter according to claim **5**, wherein when a rotation speed of said engine cannot be determined, said engagement mode is executed after a prescribed time period elapses.

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